S/α/FE ABUNDANCE RATIOS IN HALO FIELD STARS: IS THERE A GLOBULAR CLUSTER CONNECTION?

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Abstract.

We try to understand the s- and r-process elements vs Ti/Fe plots derived by Jehin et al. (1999) for mildly metal-poor stars within the framework of the analytical semi-empirical models for these elements by Pagel & Tautvaišienė (1995, 1997). Jehin et al. distinguished two Pop II subgroups: IIa with α/Fe and s-elements/Fe increasing together, which they attribute to pure SNII activity, and IIb with constant α/Fe and a range in s/Fe which they attribute to a prolonged accretion phase in parent globular clusters. However, their sample consists mainly of thick-disk stars with only 4 clear halo members, of which two are 'anomalous' in the sense defined by Nissen & Schuster (1997). Only the remaining two halo stars (and one in Nissen & Schuster's sample) depart significantly from Y/Ti (or s/α) ratios predicted by our model.

1. Introduction

The distribution of s-process abundances in stellar populations is one of the more mysterious features of Galactic chemical evolution (GCE). The problems are well illustrated in the review by McWilliam (1997) where his Figs 9 and 10 show typical s-element (Sr and Ba) to iron ratios and Ba and

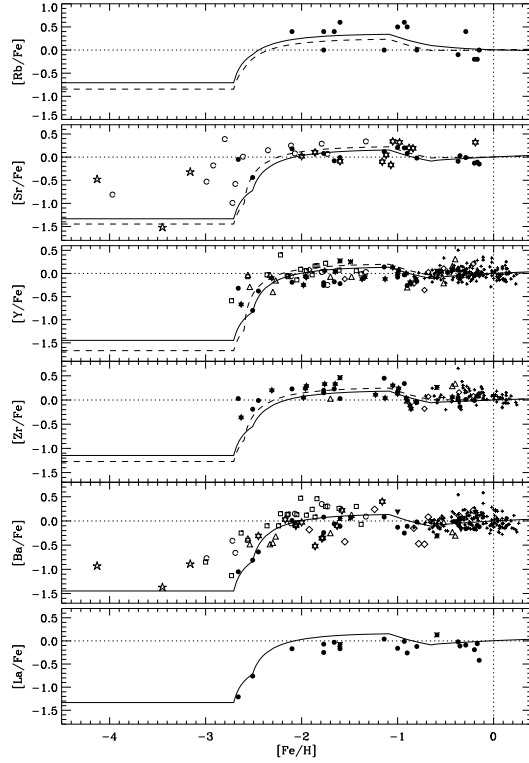*Figure 1.* s-process element-to-iron ratios as a function of [Fe/H] according to the model by Pagel & Tautvaišienė (1997).

La to Eu ratios as functions of metallicity [Fe/H], Eu being representative of a nearly pure r-process. For [Fe/H] ≤ -2.5, there is a large scatter above a lower limit [Ba/Eu] $\simeq -0.8$ representing a pure r-process, with higher values presumably due to internal mixing or contamination by a companion; but between [Fe/H] $= -2$ and about -1 there is a constant plateau with [Ba/Eu] $\simeq -0.3$, which Pagel & Tautvaišienė (1997) attributed to a general contribution to GCE of a primary s-process not readily understandable in terms of the expected age and metallicity dependence. Figs. 1 and 2 show element-to-iron ratios resulting from our *ad hoc* model, in which the s-process was treated as primary with a superposition of different time delays, noting that any secondary or other dependence of the yields on chemical composition (e.g. Travaglio et al. 1999) could be obscured by scatter in the metallicities at any given time.

In our model we supposed that the first batch of s-process synthesis came from rather massive progenitors with a typical time delay of 40 Myr corresponding to about $8.5M_\odot$ to get the plateau in Ba/Eu for $-2 \leq$ [Fe/H]
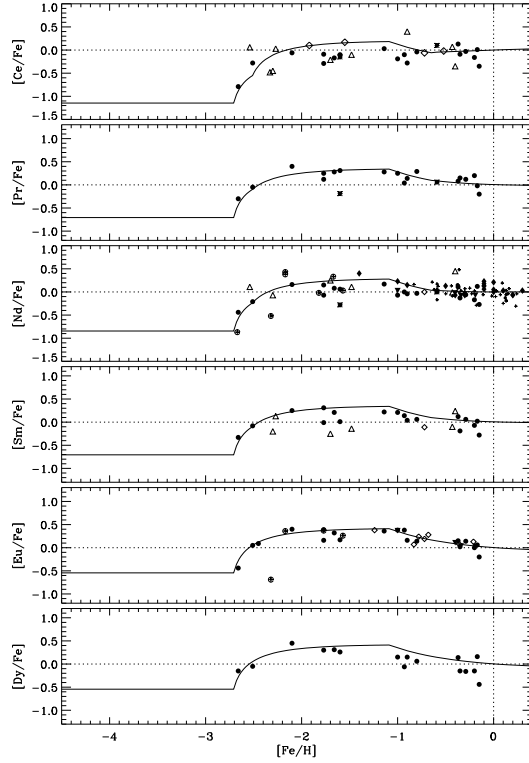
Figure 2. s- and r-process element-to-iron ratios as a function of [Fe/H] according to the model by Pagel & Tautvaišienė (1997).

< -1, long before the onset of the bulk of SNIa, and a second batch more like the conventional model for the s-process with a time delay of the order of 3 Gyr corresponding to $1.5M_\odot$ and longer than for typical SNIa leading to the decline followed by a rise in Ba/Fe that appears near solar metallicity in Fig 1. The overall fit to the data in Figs 1 and 2 is quite good, although at the lowest metallicites one should take into account the scatter in Eu/Fe that has been discussed by Tsujimoto, Shigeyama & Yoshii (1999).

In the last few years there have been substantial developments, of which we should like to mention two here:

— The work of Nissen & Schuster (1997) who investigated disk and halo stars with overlapping metallicity and found 'anomalous' halo stars which have too much iron for their content in O, α- and s-process elements represented by Y and Ba, and which might represent a slower chemical evolution such as may have occurred in the Magellanic Clouds (Pagel & Tautvaišienė 1998).

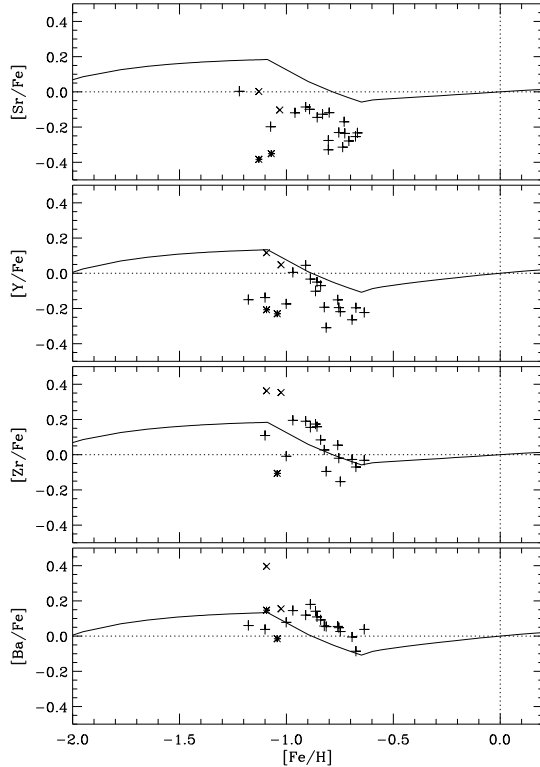— A very interesting paper by Jehin et al. (1999), where they select a

Figure 3. Data by Jehin et al. (1999) compared to the model by Pagel & Tautvaišienė (1997) for s/Fe ratios in mildly metal-deficient stars. Symbols as in Fig 4.

group of stars in the restricted metallicity range $-1.2 \leq [\text{Fe/H}] \leq -0.6$, which is again the region of metallicity overlap between the halo and thick disk and also just the range where SNIa are believed to kick in.

2. Results of Jehin et al.

Jehin et al. determined very precise abundances for a number of metals: Fe, Mg, Ca, Ti, Y, Sr, Ba and Eu, among others. However, in presenting their results they ignore metallicity as such (except in the case of Ti/Fe itself) and plot correlation diagrams [X/Fe] vs [Ti/Fe], the latter being the most accurate representative of $[\alpha/\text{Fe}]$. Thus α-elements and Eu are found to track [Ti/Fe] quite precisely, except in the case of the two 'anomalous' halo stars (in the sense of Nissen & Schuster) in their sample, which have excess europium and other r-process elements – an intriguing result not yet explained, although it may indicate the role of an r-process with a significant time delay. However, the behaviour of s-process elements was found to be different: instead of running more or less parallel to [Ti/Fe],
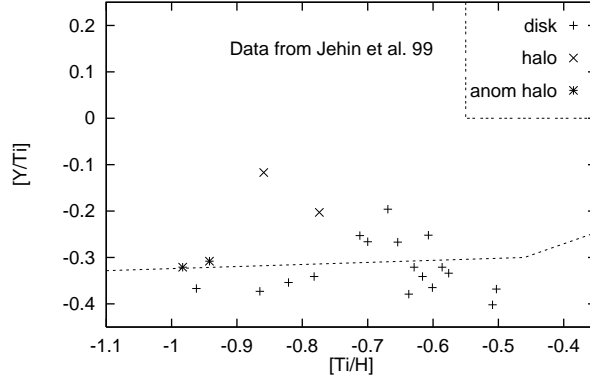
Figure 4. Data by Jehin et al. (1999) compared to the model by Pagel & Tautvaišienė (1997) for [Y/Ti] vs. [Ti/H] in mildly metal-deficient stars.

there appear to be two sequences, of which one (which they call Pop IIa and includes the 'anomalous' stars) does run more or less parallel, while the other (which they call Pop IIb) starts at the end of the previous sequence and then runs up vertically at [Ti/Fe] = 0.24. This inspired the authors to put forward what they call the EAS scenario — Evaporation, Accretion, Self-enrichment — in which all halo and thick-disk stars are assumed to form in globular clusters or proto-clusters undergoing chemical evolution. Some clusters were disrupted at an early stage leading to Pop IIa with pure SNII ejecta, whereas others lasted longer enabling dwarf stars to accrete s-process material from nearby AGB stars before the clusters evaporated, leading to Pop IIb.

3. Relation with metallicity

While the hypothesis of Jehin et al. is interesting and possibly even right, we do not think their results can be understood without looking at the data as a function of metallicity; this is done in Fig 3 which distinguishes stellar population types and also presents the model by Pagel & Taut-vaišienė (1997). The upper 7 or 8 stars in each panel are Type IIb and the 'anomalous' stars appear near bottom left.

    According to our model, there is an overall downward trend due to the impact of Type Ia supernovae contributing extra iron in just this range of metallicity, and that is nicely confirmed by the mean trend of the new data, although the absolute fit is better for some elements than for others, and the results of Jehin et al. appear to be a scatter around this trend, possibly related to their scenario, whereas Ti/Fe reaches a sharply defined plateau
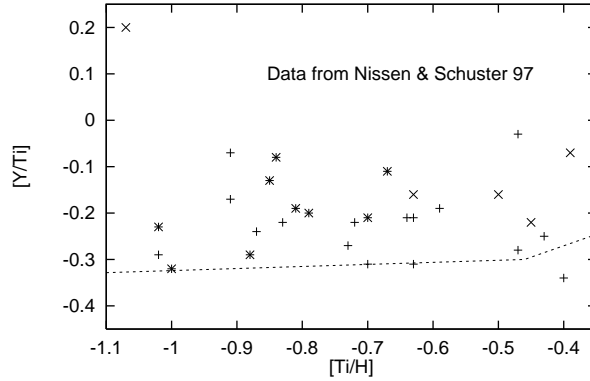
Figure 5.   Data by Nissen & Schuster (1997) compared to the model by Pagel & Taut-vaišienė (1997) for [Y/Ti] vs. [Ti/H] in mildly metal-deficient stars. Symbols as in Fig 4.

representing pure SNII production on the low-metallicity side, where the s-process points spread out forming a wedge-shaped distribution.

How much of this represents really significant deviations from conventional GCE? To investigate this point, we have plotted in Fig 4 what seems to be the best determined s-process result, [Y/Ti], against [Ti/H], which is chosen as the best available 'clock' (cf. Wheeler, Sneden & Truran 1989). Fig 5 shows corresponding data from the paper by Nissen & Schuster, where scatter in the determinations is somewhat greater, but one star appears as a still more extreme case of Jehin et al.'s Pop IIb. The dotted line in each case shows the prediction of our model. We feel that the departure of any thick-disk or anomalous-halo stars in these samples from our model predictions in this plane are at most marginal, but the effect discovered by Jehin et al. is certainly there among at least some of the non-anomalous halo stars. Clearly more and better statistics would be useful.

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